

*Reprinted from the Proceedings of the
Specialty Conference on Environmentally Sound Water and Soil Management
ASCE/Orlando, Florida/July 20-23, 1982*

SCHEDULING IRRIGATION IN THE SOUTHEAST

WITH A SCREENED EVAPORATION PAN

C. W. DOTY, C. R. CAMP and G. D. CHRISTENBURY^{1/}

ABSTRACT

A modified screen-covered evaporation pan served as a physical simulator to schedule irrigation for a center pivot system and screened pan evaporation was used to estimate PET in a manual water balance method. Corn and soybean yields for treatments where irrigation was scheduled using these techniques were significantly higher than yields for nonirrigated treatments. These results indicate that both techniques provide acceptable irrigation scheduling precision for corn and soybeans in the humid Southeast and are practical enough to be acceptable to most farmers.

INTRODUCTION

The total number of estimated drought days (days when soil moisture is not sufficient to meet ET demands) expected 2 out of 10 years in the Coastal Plains of South Carolina is 9 days in May, 16 in June, 15 in July, 10 in August, and 9 days in September (van Bavel et al. 1957). These droughts are the result of erratic rainfall, ranging from 700 to 1940 mm annually and from 0 to 350 mm, monthly. Also, the sandy loam soils with water-holding capacities that range from 20 to 50 mm water/30 cm of soil provide water to supply crop needs for only 5 to 10 days. Pressure to increase crop production and profit have amplified interest in irrigation in the Southeast in recent years.

With the exception of maximum and minimum temperatures, the most widely available meteorological data that can be used in irrigation scheduling is pan evaporation. These data are collected daily at each Class A weather station operated by the National Weather Service. An irrigation scheduling method based on pan evaporation data could be adapted over a large area in the vicinity of the weather station.

Potential evapotranspiration (PET) is the rate at which water is transferred from plant and soil surfaces to the atmosphere when the water is readily available, as in the case of a well-watered crop. PET is usually calculated using empirical equations (Penman 1948, van

^{1/} Agricultural Engineer, Agricultural Engineer, USDA/ARS, Coastal Plains Soil and Water Conservation Research Center, Florence, S.C., and Assoc. Prof., Clemson Univ. Extension Service, Florence, S.C.

Bavel 1966, Bartholic et al. 1970, Jensen 1974). Van Bavel and Wilson (1952) showed that the actual evapotranspiration (ET) from a crop canopy was within the range of that calculated by the empirical equations. Campbell and Phene (1976) found that a 5-cm mesh wire screen cover over a USNWS Class A pan reduced evaporation 12.8% below that of an open pan and that the relationship between screened pan evaporation (SPE) and evapotranspiration computed from the combination equation was nearly 1:1 (van Bavel 1966, and Tanner and Pelton 1960), when the roughness length parameter $z_0 = 1$ in the wind term was used. Therefore screened pan evaporation measurements can be used for estimating daily ET values which we have defined as PET for this study. The use of PET as a method of estimating moisture uptake by the crop from the soil has been proposed by numerous authors including van Bavel (1952, 1956, 1957, 1959, 1966) and Burman et al. (1980). By accounting for the excess water, the daily storage of water in the soil profile can be predicted by multiplying daily screened pan evaporation (assumed PET) by a crop coefficient (Doty 1980). Bouwer (1959) proposed using the open pan as a method for scheduling irrigation. The objectives of this paper are: (1) to use the screened evaporation pan as a physical simulator (SPE-simulator) for a water budget to schedule irrigation, (2) to develop irrigation scheduling methods using pan evaporation for estimating potential evapotranspiration (PET), and (3) to evaluate the effects of these scheduling methods on crop yield and the resulting water status in the soil.

PROCEDURES AND EXPERIMENTAL SITES

Evaporation from a screen-covered pan was used in two different techniques to schedule irrigation. The screen-covered pan was used as a physical simulator of the soil-water balance, and daily evaporation from the screen-covered pan was used to estimate PET in a manual water balance procedure. In this paper, the terms SPE-simulator and water balance, respectively, will be used to identify the two methods.

SPE-Simulator - A Physical Simulator to Schedule Irrigation

A screen-covered USWB Class A evaporation pan was modified to simulate automatically the water balance and indicate the time and amount of irrigation required. The pan was modified by installing an overflow device to remove excess water and by attaching a stainless steel scale to the side of the pan to indicate water level changes (Fig. 1).

Three inputs required in most scheduling techniques are rooting depth, irrigation system efficiency, and soil water storage to be depleted before irrigation is applied (allowable depletion). Two assumptions which are required when using the screened evaporation pan to schedule irrigation are (1) screened pan evaporation is equal to PET and (2) water from rainfall or irrigation in excess of soil storage is lost either as runoff or deep percolation.

The details of the SPE-simulator method can best be explained through the use of an example. The center pivot system used in this study irrigates an area including 3 soil series; Raines, 10%; Norfolk,

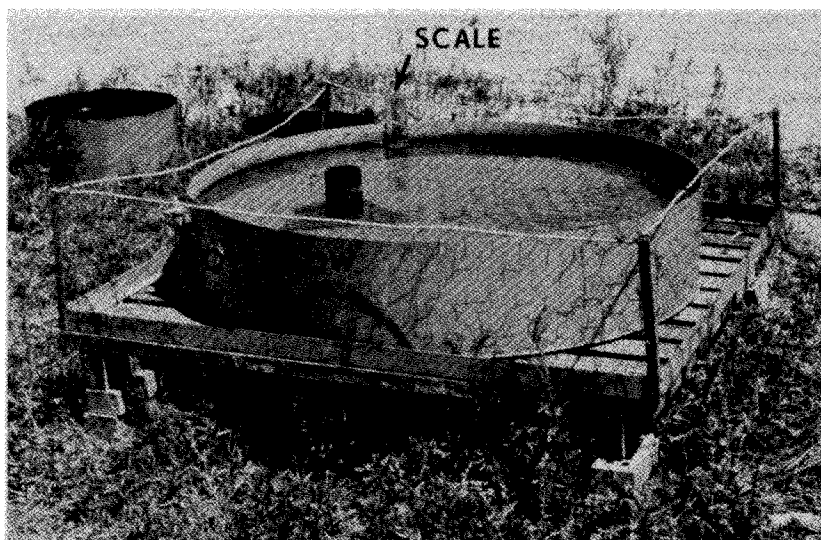


Figure 1. Evaporation pan modified with a screen, overflow, and scale to physically simulate a water balance to schedule irrigation for a center pivot system.

40%; and Wagram, 50%. The irrigation system efficiency is 80% and the crop is corn. The feeder root depth for corn was assumed to be 76 cm (Sprinkler Irrigation Handbook, 1970), and irrigation was to be applied when 50% of the available water in the rooting zone was depleted. The available water capacities for the soil were calculated using data from the Soil Conservation Service, National Cooperative Soil Survey, Blue Sheets of soil series descriptions. The available water in the 76-cm rooting zone on the Norfolk, Wagram, and Raines soils is 74 mm, 58 mm, and 87 mm, respectively. However, since the Wagram series has the lowest volume of water available and comprises 50% of the area, it was the governing soil for determining when irrigation was needed. The three soils in the study area have a maximum difference of 15 mm of water in the allowable depletion, which means that the Raines soil was irrigated 2 or 3 days earlier than needed or at an allowable depletion of 33%, but was not irrigated in excess of profile storage. The Norfolk soil in our study was irrigated at an allowable depletion of 39%. Therefore, irrigation water was applied when 29 mm = 58 mm x 50% cm of water was depleted from the soil.

The amount of water to be applied at each irrigation was determined using the equation, $I = (AW)(AD)/E$ where I is the amount of irrigation water to be applied, AW is the volume of available water in the rooting zone, AD is the allowable depletion or fraction of available water used by evapotranspiration before irrigation is needed, and E is the irrigation system efficiency. Therefore, for

this case, $I = (58)(.5)/0.8 = 36 \text{ mm}$.

The amount of pan evaporation required before irrigation was determined by the equation, $PE = (AW)(AD)/C$ where PE is the pan evaporation required before irrigation is needed, and C is a crop coefficient relating actual ET to PET. In this study, $C = 0.6$ was used for corn from emergence to 50 cm plant height and $C = 1.0$ until physiological maturity. For soybeans, irrigation was begun at crop canopy closure using $C = 1.0$ and was continued until physiological maturity. These values were adapted from the curves given in SCS Technical Release No. 21, 1970. Therefore, during the later part of the season $PE = (58)(.5)/1.0 = 29 \text{ mm}$.

The SPE-simulator procedure was initiated when the soil water storage was maximum, one or two days after a rain or irrigation that filled the soil profile. The pan was leveled, filled with water until it overflowed, and allowed to reach equilibrium. The metal scale, inserted into the water to the depth of the allowable depletion (29 mm in this study) along the side of the pan, was secured with the a clamp. The water depth in the screened pan was observed daily, and when the water level dropped to the end of the scale, the allowable water was estimated to have been depleted from the profile. Water (36 mm in this study) was then applied by the irrigation system to replace the depletion water. Similarly, the SPE-simulator simulated the water balance for the entire season. If rainfall occurred, the water level in the pan rose simulating an increase in available soil water. Rainfall in excess of soil storage was removed from the pan by the overflow. For sprinkler irrigation systems, the SPE-simulator may be placed under the irrigation system where it will receive all water that falls on the area. If the pan is not located under a sprinkler system, it must be manually filled to the overflow point after each irrigation (provided the soil water storage is fully replenished).

Water Balance Method

Initially the amount of water allowed for depletion in the root zone was determined, the amount of water removed by the plants ($SPE \times C$) each day was subtracted and rainfall, if any, was added until the soil storage was depleted, at which time irrigation was applied (Bruce et al., 1980; Doorenbos and Pruitt, 1977). This method requires the same assumptions and installation requirements as the first method. The balance sheet used in keeping records and making calculations is given in Figure 2.

Rainfall was measured at the site of the irrigation system. The allowable depletion and the amount of water to be applied at each irrigation is the same as in the SPE-simulator method and is shown at the top of Figure 2. The comments and explanatory notes annotated on Figure 2 explain the procedure for calculating the water balance using SPE for PET and shows how the water balance can be used to determine when to irrigate and the volume of water to apply. This method requires only one evaporation pan for several different crops or irrigation systems, but requires a separate balance sheet for each

month and each crop or irrigation system. The evaporation from the screened pan must be measured at least three times a week (preferably daily) in order to account for moisture loss. When the National Weather Service open pan is used, evaporation should be multiplied by 0.88 to obtain SPE (for Column 6, Fig. 2) (Campbell and Phene, 1976).

Daily Water Balance Record

Field _____	Crop _____	Mo/Yr _____	/	Rooting Depth _____	
(1) Available Water _____	X	(2) Allowable Depletion _____	X		
(3) Replacement Fraction _____	+	(4) Application Efficiency =			
Irrigation to Apply _____.					

Day of Mo.	Depletion Storage for day n-1 (5)*	Screened Pan Evaporation (6)	Crop Coef. (Fraction of PET) (7)	ET (8)	Rain or Irrig. (9)	Depletion Storage for Day n (10)
	----- (11) inches-cm-mm -----					
1						
2						
3						
.						
.						
.						
31						

*(5) Depletion storage on day n-1 or soil water available for depletion on day n-1. Water volume added in excess of (1) X (2) exceeds storage and will be lost to runoff or percolation. Values in column (5) can be = (1) X (2) following rainfall or irrigation and should be (1) X (2) to begin season.

(6) Evaporation from screen-covered pan or 0.88 X Weather Bureau evaporation.

(7) Crop coefficient, K_c , curve No. 20, for soybeans, from USDA-SCS Technical Release No. 21 was used in this study.

(8) Evapotranspiration (ET) = (6) X (7).

(9) Rainfall or irrigation since last reading.

(10) (5) - (8) + (9) = (10) depletion storage for day n (the day of the observation - if less than 0.1, then irrigate).

(11) Metric or English can be used. Cross out units not used.

Fig. 2. Daily water balance record for use with a screen-covered evaporation pan.

Field Experiments

The screened evaporation pan was used to schedule irrigation for two sites, a center pivot system with corn and soybeans and a trickle system with soybeans. The SPE-simulator method was used to schedule irrigation under a center pivot system for four years (1978-81). Two quadrants of the center pivot system were used in this study with one

quadrant planted to corn and the other to soybeans. These two crops were rotated annually so that they were alternated on a given quadrant. Nonirrigated plots were located immediately adjacent to the irrigated area. Four replications were included for all treatments. All plots were in-row subsoiled and planted in a single operation. Both corn and soybeans were planted in 1979-1981, but only soybeans (planted May 9 and May 24) were planted in 1978. Tensiometers were installed in all plots and read three times each week. Corn and soybeans were harvested by combine and yield measurements made from 120 m of row for plots under the center pivot system.

The water balance method was used to schedule trickle irrigation for a soybean experiment where in-row subsoiling tillage practices were used. The irrigation treatments were (1) nonirrigated, and (2) trickle irrigation supplying 75% of the water depleted. Screened pan evaporation was used as PET. Tensiometers were placed in all plots and read three times each week. Also, soybean were combined and yields measured for 30 m of row in plots under trickle irrigation.

RESULTS AND DISCUSSION

Water received by corn and soybeans each growing season in 1979, 1980, and 1981 by the SPE-simulator method and the water balance method is shown in Table 1.

Table 1. Water received by crops during the growing season from rainfall and irrigation scheduled by two methods.

Source of Water	Rainfall-Irrigation Amount			
	1979	1980	1981	Mean
-----mm-----				
----Corn, SPE-Simulator, Center Pivot System----				
Rainfall	474	297	435	402
Irrigation	192	256	179	209
---Soybeans, SPE-Simulator, Center Pivot System---				
Rainfall	726	433	521	560
Irrigation	198	349	178	242
---Soybeans, Water Balance, Trickle System---				
Rainfall	690	364	445	500
Irrigation	146	282	286	238

Irrigation water applied to corn using the SPE-simulator scheduling method generally varied inversely with rainfall received during the growing season. When we analyzed corn irrigation scheduled by the SPE-simulator for the 3-year period with respect to the lapsed time between receipt of at least 10 mm of water and an irrigation, we found that the lapsed time ranged from 3 to 10 days. Most irrigation applications (58%) were made within 5 to 7 days after receiving at least 10 mm of water (irrigation or rainfall). Over the 3-year period,

water was applied 17 times.

Soybeans irrigated using the SPE-simulator scheduling method received 194 mm more total water in 1979 than in 1981, but irrigation accounted for only 20 mm of the difference (Table 1). Rainfall was 293 mm less in 1980 than in 1979 while the water applied by irrigation was 151 mm greater. The SPE-simulator performed satisfactorily under these widely varying climatic conditions.

Water applied by trickle irrigation scheduled by the water balance method also varied considerably, from 146 mm in 1979 to 289 mm in 1980 (Table 1). Much of the high rainfall received in 1979 occurred in several large rainfall events in July, August, and September which caused excessively wet soil.

Corn yields for plots with center pivot irrigation scheduled with the SPE-simulator were significantly greater than yields for nonirrigated plots for all years (Table 2). SPE-simulator scheduled irrigation increased the 3-year mean corn yield by 81% or 0.019 t/ha for each mm of irrigation applied.

In 1978 soybean yields of 2.60 and 1.96 t/ha from the early and late beans, respectively, were significantly greater than the non-irrigated yields of 1.78 and 1.28 t/ha, respectively. Soybean yields (Table 2) for the irrigated plots were significantly higher each year than those for the nonirrigated. The 3-year average (1979-1981) showed that irrigation increased yields 66% or by 0.004 t/ha for each mm of irrigation applied.

Table 2. Crop yield for nonirrigated and two irrigation scheduling techniques.

Treatment	Yield			
	1979	1980	1981	Mean
-----t/ha-----				
---Corn, SPE-Simulator, Center Pivot---				
Nonirrigated	6.47 b*	2.99 b	4.90 b	4.79 b
Irrigated	10.90 a	6.05 a	9.13 a	8.69 a
---Soybeans, SPE-Simulator, Center Pivot---				
NonIrrigated	1.50 b	1.38 b	1.59 b	1.51 b
Irrigated	2.61 a	2.40 a	2.39 a	2.39 a
---Soybeans, Water Balance, Trickle System---				
Nonirrigated	2.53 a	0.83 b	1.85 b	1.49 b
Irrigated	1.98 b	1.92 a	2.03 a	1.98 a

* Yields followed by the same letter in a column within a scheduling method are not significantly different by DMR Test at $P = .05$.

Yields of soybean that were trickle irrigated by the water

balance scheduling method are shown in Table 2. The 1979 yield results indicate that when rainfall occurs at a favorable time, irrigation was not needed and that under certain conditions, irrigation can actually decrease yields. Excess rainfall caused oxygen stress in the irrigated plots. In 1980 and 1981 soybean yields for irrigated treatments were significantly higher than those for nonirrigated. The water balance scheduling method increased the 3-year average soybean yield by 33% over the nonirrigated treatment or by 0.002 t/ha for each mm of irrigation applied.

The effectiveness of the SPE-simulator for scheduling irrigation for corn and soybeans is reflected by the soil water suction values which were maintained within the 40 cm limit. The soil water control for the trickle irrigation system scheduled by the water balance method was adequate. Refinement of the crop coefficient should be considered because the method appeared to under irrigate soybeans early in the season and over irrigate during the latter part of the season. This was indicated by the high soil water suction in June and July and low suction in August, September, and October.

CONCLUSIONS

The SPE-simulator method provides irrigation requirements that are near the operational precision of most irrigation systems. Refinements in crop coefficient values are needed to more precisely estimate daily ET for crops of the Southeast. The results of this study demonstrate the importance of precise irrigation scheduling in the Southeast. The methods evaluated provide acceptable irrigation scheduling precision for corn and soybeans and are practical enough to be acceptable to most farmers.

REFERENCES CITED

- Bartholic, S.F., L. N. Namken, and C. L. Wiengard. 1970. Combination equation used to calculate evaporation and potential evapotranspiration. U.S. Dept. Agric., ARS-41-1, 170:14 pp.
- Bouwer, Herman. 1959. Integrating rainfall-evaporation recorder. ASAE J. 40:278
- Burman, R. D., P. R. Nixon, J. L. Wright, and W. O. Pruitt. 1980. Water Requirements In: Design and Operation of Farm Irrigation Systems, M. E. Jensen (Ed.). Am. Soc. Agric. Eng., St. Joseph MI, pp. 189-232.
- Bruce, R. R., J. L. Chesness, T. C. Keisling, J. E. Pallas, Jr., D. A. Smittle, J. R. Stansell, and A. W. Thomas. 1980. Irrigation of crops in the southeastern United States - Principles and Practice. USDA/SEA, ARM-S-9.
- Campbell, R. B., and C. J. Phene. 1976. Estimating potential evapotranspiration from screened pan evaporation. Agric. Meteorol., 16: 343352.
- Doorenbos, J., and W. O. Pruitt. 1977 Crop water requirements. FAO Irrigation and Drainage Paper No. 24, Rome, Italy.
- Doty, C. W. 1980. Crop water supplied by controlled and reversible drainage. Trans. ASAE. 23(5):1122-1130.
- Fry, A. W. and A. S. Gray. 1970. Sprinkler irrigation handbook.

- Ninth Edition, Rainbird Sprinkler Mfg. Corp., Glendoro, CA.
- Jensen, M. E. (Ed.) 1974. Consumptive use of water and irrigation water requirements. Rep. Tech. Com. on Irrig. Water Requirements, Am. Soc. Civ. Eng., Irrig. Drain. Div., 227 p.
- Penman, H. L. 1948. Natural evaporation from open water, bare soil and grass. Proc. R. Soc. Land. Serv. A. 193:120-145
- USDA, Soil Conservation Service. 1970. Irrigation water requirements. Tech. Release No. 21. USDA-SCS, Engr. Div., Washington, DC.
- van Bavel, C. H. M. 1956. Estimating soil moisture conditions and time of irrigation with the evaporation method. U.S. Department of Agriculture, Agricultural Research Service, ARS-41-11.
- van Bavel, C. H. M. 1959. Practical use of knowledge about evapotranspiration. Trans. ASAE 2(1):39-40
- van Bavel, C. H. M. 1966. Potential evaporation: the combination concept and its experimental verification. Water Resour. Res. 2:455-467.
- van Bavel, C. H. M., and T. V. Wilson. 1952. Evapotranspiration estimates as criteria for determining the time of irrigation. ASAE J. 33:417-420.
- van Bavel, C. H. M., L. A. Forrest, and T. C. Peele. 1957. Agricultural drought in South Carolina. S.C. Agri. Exp. Station, Clemson University Bull. 447.